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NAVAL MEDICAL RESEARCH INST BETHESDA MD
TRIMIX AT DEPTHS BELOW 1000 FSW.(U)
1976 A J BACHRACH, M J ACKERMAN

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) TRIMIX AT DEPTHS BELOW 1000 FSW		5. TYPE OF REPORT & PERIOD COVERED Medical Research Progress Report no. 6
6. AUTHOR(s) A. J./Bachrach, M. J./Ackerman, P. B./Bennett, and D./Burgess		7. PERFORMING ORG. REPORT NUMBER
8. CONTRACT OR GRANT NUMBER(s)		9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MPN10.03-3015 Report No. 6
10. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Medical Research Institute Bethesda, Maryland 20014		11. REPORT DATE 11 1976
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Medical Research & Development Command Bethesda, Maryland 20014		12. NUMBER OF PAGES 3 pp.
12. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Bureau of Medicine and Surgery Department of the Navy Washington, D.C. 20372		13. SECURITY CLASS. (of this report) UNCLASSIFIED
13a. DECLASSIFICATION/DOWNGRADING SCHEDULE		
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release and sale; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) DDC RECEIVED NOV 28 1977 RECEIVED		
18. SUPPLEMENTARY NOTES Bachrach, A. J., M. J. Ackerman, P. B. Bennett, and D. Burgess. 1977. Trimix at depths below 1000 fsw. Proceedings, International Diving Symposium 1976, January 22-23, 1976, New Orleans, La. Association of Diving Contractors, Belle Chasse, La. pp. 45-47.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) high pressure nervous syndrome; hyperbaric environment; compression rate; helium-oxygen-nitrogen [breathing mixture]; humans		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Previous research in a series of chamber dives at the Duke University Medical Center Hall Laboratory has suggested that 9 to 10 per cent nitrogen in a heliox trimix can prevent the high pressure nervous syndrome (HPNS) in rapid compression (33 min) to 305 m (1000 fsw). The dives reported here were planned to investigate the same partial pressure of nitrogen (3.5 ATA) at 396 m (1300 fsw) and 488 m (1600 fsw), but at 464 m (1521 fsw), fatigue, dizziness, and nausea were such that compression was terminated. It had been hoped that a lower nitrogen percentage plus a slower compression rate would reduce any		

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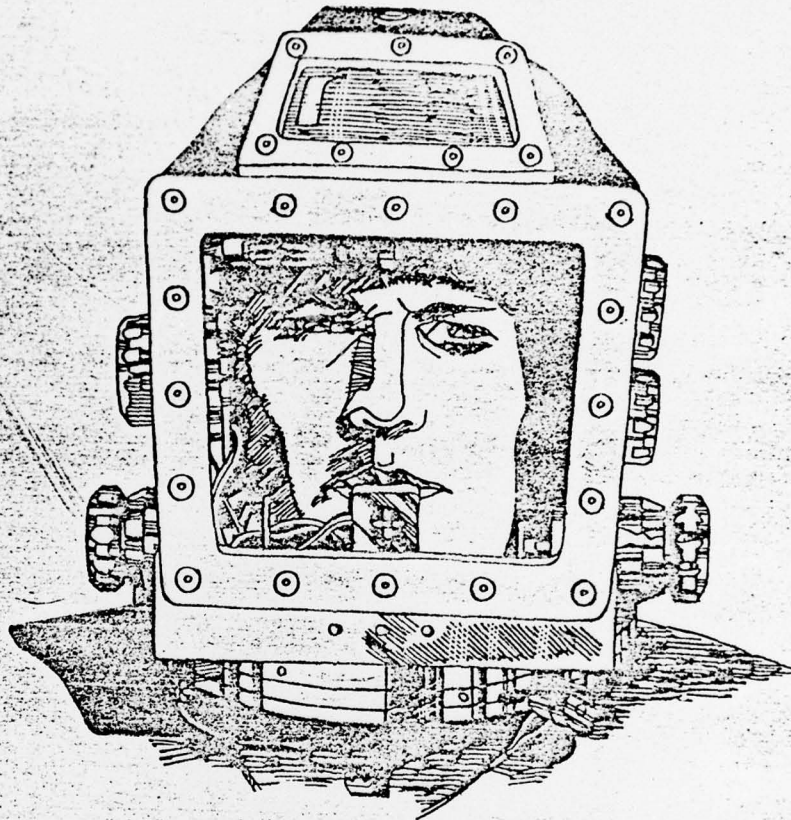
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possible respiratory problems as well as the HPNS. At 6 percent nitrogen, however, with a compression rate to 400 m (1312 fsw) of 2 h, HPNS occurred along with fatigue, confusion, dizziness, and slight nausea. Performance tests indicated a -55 percent mean decrement for mathematics, improving to -42 percent over 2 h and the ball bearing test showed improvement from -25 to -10 percent. The EEG showed increased theta activity; intentional tremor increased by 80 percent from atmospheric controls. At 5 percent nitrogen, compression was made toward 1600 fsw at a slower rate, with 150 min to 1312 fsw and a 20-min stage there. At 1312 fsw the divers felt good with much less HPNS. The mathematics test indicated a decrement of -31 percent; the ball bearing test indicated -42 percent. On compression to 1521 fsw the divers became fatigued, sleepy, and nauseated; theta activity increased; and intentional tremor rose 160 percent. Decompression was started at 1521 fsw. The results of these dives agree with the theory established in the earlier dives: nitrogen percentages less than 9 percent, even with a moderate compression rate, are not effective in preventing HPNS at depths deeper than 1000 fsw. Recently, however other investigators have reported contrasting results on 9 percent trimix at 300 m (985 fsw). Further research should investigate the possibility that the amount of nitrogen needed to antagonize the HPNS varies with rate of compression.

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Trimix At Depths Below 1000 FSW

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ABSTRACT

Previous research in a series of chamber dives at the Duke University Medical Center Hall Laboratory has suggested that 9 to 10 per cent nitrogen in a heliox trimix can prevent the high pressure nervous syndrome (HPNS) in rapid compression (33 min) to 305 m (1000 fsw). The dives reported here were planned to investigate the same partial pressure of nitrogen (3.5 ATA) at 396 m (1300 fsw) and 488 m (1600 fsw), but at 464 m (1521 fsw), fatigue, dizziness, and nausea were such that compression was terminated. It had been hoped that a lower nitrogen percentage plus a slower compression rate would reduce any possible respiratory problems as well as the HPNS. At 6 per cent nitrogen, however, with a compression rate to 400 m (1312 fsw) of 2 h, HPNS occurred along with fatigue, confusion, dizziness, and slight nausea. Performance tests indicated a -55 per cent mean decrement for mathematics, improving to -42 per cent over 2 h and the ball bearing test showed improvement from -25 to -10 per cent. The EEG showed increased theta activity; intentional tremor increased by 80 per cent from atmospheric controls. At 5 per cent nitrogen, compression was made toward 1600 fsw at a slower rate, with 150 min to 1312 fsw and a 20-min stage there. At 1312 fsw the divers felt good with much less HPNS. The mathematics test indicated a decrement of -31 per cent; the ball bearing test indicated -42 per cent. On compression to 1521 fsw the divers became fatigued, sleepy, and nauseated; theta activity increased; and intentional tremor rose 160 per cent. Decompression was started at 1521 fsw. The results of these dives agree with the theory established in the earlier dives: nitrogen percentages less than 9 per cent, even with a moderate compression rate, are not effective in preventing HPNS at depths deeper than 1000 fsw. Recently, however, other investigators have reported contrasting results on 9 per cent trimix at 300 m (985 fsw). Further research should investigate the possibility that the amount of nitrogen needed to antagonize the HPNS varies with rate of compression.

A number of recent chamber experiments have indicated that the problem of the HPNS or high pressure nervous syndrome (Bachrach and Bennett 1973; Hunter and Bennett 1974), found during oxygen-helium diving deeper than 152 m (500 fsw), may be mitigated by incorporating nitrogen (or another anesthetic) into the mixture. It is believed this effect is due to the fact that under high pressures of helium, cell membranes (including those in the brain) are compressed, whereas under anesthesia and nitrogen they are expanded (Miller, Paton, Smith, and Smith 1973; Bennett 1975). Thus, the correct proportion of each gas should result in normal cell membranes and no HPNS or narcosis.

Research at Duke University Medical Center has

suggested that the correct amount of nitrogen appears to be about 9 to 10 per cent (Simon, Katz, and Bennett 1975); chamber experiments exposing men to 305 m (1000 fsw) in 33 min with trimix (helium, oxygen and 10 per cent nitrogen) showed no narcosis or HPNS performance decrement. Earlier similar dives to 1000 fsw with 18 per cent nitrogen showed control of HPNS, but nitrogen narcosis was present (Bennett, Blenkarn, Roby, and Youngblood 1974).

During June 1975 further chamber studies were made by the team at Duke University Medical Center in conjunction with the group at the Naval Medical Research Institute to investigate the effects of breathing trimix at depths greater than 1000 fsw. This work was carried out under contract by the Duke University Medical Center at the Royal Naval Physiological Laboratory, using divers from Oceaneering International, Inc., as subjects.

PROCEDURES AND RESULTS

Exposure of Two Men to 1300 fsw Breathing Trimix (6 per cent N₂)

The first experiment beyond 1000 fsw involved compression to 1300 fsw of two divers who had served as subjects in the earlier studies to 1000 fsw. Compression time was 2 hours with short stages. The compression rate was slowed on the following schedule: 18 m/min to 98 m; 6 m/min to 305 m; and then 3 m/min to 400 m (1312 fsw). The decompression profile is shown in Table 1; it required 6 days plus 4½ hours.

A 6 per cent nitrogen percentage in the trimix at 1312 fsw was chosen, which was the same partial pressure used in the earlier 1000-fsw dive. Although theory established on the earlier dives dictates a constant percentage (which would be between 3 and 10 per cent), it was decided to decrease the percentage to reduce possible risks of undue nitrogen narcosis at 1312 fsw and to reduce the density of the breathing mixture. Investigators estimated that a relatively slow rate of compression to 1312 fsw (requiring 40 min from 1000 fsw), combined with the slightly lower nitrogen partial pressure, might be sufficient to control the HPNS.

In practice, however, such was not the case and signs and symptoms of HPNS resulted. In particular, there was evidence of undue fatigue and confusion, accompanied by dizziness, lightheadedness, and slight nausea.

The performance results indicated for the mathematics test a mean decrement of -55 per cent on arrival at 1300 fsw and a small improvement to -42 per cent before decompression. The ball bearing test results indicated a mean reduction from controls of -25 per cent, recovering to -10 per cent after 2 hours at 1312 fsw.

The electroencephalogram (EEG) and tremor

results showed evidence of an increase in slow wave theta activity (4-7 Hz), especially in one of the two subjects, and an increase in the amount of tremor in both.

The decompression was very satisfactory with little arthralgia or "niggles." Indeed, the divers indicated that the table was one of the most comfortable they had ever used for decompression. The decompression for the 1300-fsw diver took 6 days plus 4½ hours.

Exposure of Two Men to 1600 fsw Breathing Trimix (5 per cent N₂)

On the basis of the knowledge gained from the 1312-fsw exposure, investigators believed that the problems could be solved either by slowing the rate of compression or by increasing the nitrogen partial pressure. Because of the fatigue seen in the two divers at 1312 fsw, it was decided that a slower rate of compression should be tested first; this decision was based on a correlation between these two parameters reported by French investigators (Fructus, Agarate, and Sicardi in press). Thus, the dive was planned to 1600 fsw, with a nitrogen partial pressure of 5 per cent, which had previously been tested at 1000 fsw. The compression profile was modified to 150 min to reach 1312 fsw, compared with the 100 min of the previous dive. After a 20-min stage at 1312 fsw, compression was resumed at 1 m/min.

The slower compression to 1312 fsw was very advantageous and the two divers reported feeling much better than during the previous exposure to this depth. Although they reported feeling less HPNS, they were very troubled by the heat of compression and did experience some lightheadedness and mild dizziness. Compression was hot because of the nature of the temperature control system at the RNPL (31.5 degrees C) and because there was a heat wave with air temperatures registering in the 80's.

In light of the animal studies reported elsewhere (Cromer, Hunter, and Bennett in press), the role of increased temperature in exacerbating HPNS must be considered. However, by 1300 fsw the decrement of -31 per cent on the mathematics test was much less than the previous -55 per cent, and the decrement of -24 per cent on the ball bearing test was much less than the previous -42 per cent. It should be pointed out that in this dive, as in the French dives, if marked fatigue was experienced, then full performance recovery did not appear until the diver approached the surface. After the tests at the 1312-fsw stage, compression was resumed.

During the compression at 1 m/min toward 1600 fsw, the divers became slow in cerebration and movement, giving indications of fatigue and sleepiness. At 1521 fsw one of the divers insisted on getting out of his chair and stretching out on the chamber floor due to the dizziness and fatigue. At this point the compression was stopped and decompression commenced since the divers were obviously not in a fit condition to work. The decompression proceeded without problems and the divers recovered quickly.

DISCUSSION AND SUMMARY

Theoretically, if the divers had waited at 1512 fsw, the signs and symptoms would have abated. Nevertheless, it is clear that working divers could

not be exposed regularly to such conditions until much more is known about the nature of the HPNS and its effects on the central and peripheral nervous systems. We recognize that it is not unusual for divers to perform gross motor tasks at depth, as happened in the COMEX chamber dives and in the recent University of Pennsylvania dives. But, we are still concerned with the physiological and long-term effects of HPNS.

In the Philadelphia dive, Spencer, Findling, Bachrach, and Karreman (1976) reported that certain symptoms of HPNS (nausea, fatigue, tremor, and balance disturbances) were evident on the first day, when 1200 fsw was reached. By the second and third day, while compressing to 1600 fsw and decompressing back to 1200 fsw, tremor and balance disturbances were still evident. In many of the studies on HPNS the questions about long-term effects or how well the divers can respond in case of an emergency still need to be answered.

This series of deep dives at Duke University and the Royal Naval Physiological Laboratory has demonstrated that 9 to 10 per cent appears to be a reasonable nitrogen partial pressure for fast compression (30 min) to 1000 fsw to reduce HPNS, but that the same partial pressure is not as effective at greater depths. In contrast, Rostain, Naquet, and Fructus (1976) report testing the trimix at 4.5 and 9 per cent N₂, as well as the heliox, on dives to 300 m (985 fsw); their dives had identical compression characteristics (duration: 4 hours; 0-100 m at 4 m/min; 100-240 m at 2 m/min; 240-300 m at 1 m/min. All dives had a 30-min rest stage at 100, 180, and 240 m.) Rostain, et al. state that both 4.5 and 9 per cent N₂ were far from being sufficient to bring about a noticeable improvement in classical EEG modifications of the HPNS and that divers manifested paroxysmic EEG modifications never seen with heliox. Such spindle-burst activity was seen also in one of the divers during the present study while compressing to 1521 fsw. They further state that in every case the subjects were unable to work on arrival at 300 m (985 fsw).

The differences between the findings in the Rostain et al. dives and the Duke-RNPL dives need further investigation. Perhaps the difference is due not only to the hydrostatic pressure but also to the compression rate. The French dives to 985 fsw used a 4-hour compression rate, while the Duke-RNPL dives were faster, with a 33-min compression to 1000 fsw. It may be that the amount of nitrogen needed to antagonize the HPNS varies with the rate of compression. Thus, the 4-hour compression in the French dives may have induced less HPNS than the Duke 33-min compression and 9 per cent may have been too much nitrogen for the slower rate of compression.

More research is required to ascertain if the 9 to 10 per cent is suitable at depths greater than 1000 fsw or whether nitrogen narcosis will be too great. With the advent of shorter successful decompression times, it is perhaps not unreasonable to lengthen the compression times further.

ACKNOWLEDGMENTS

Supported by Naval Medical Research and Development Command, Navy Department, Research Subtask MPN10.03.3015. The opinions and statements contained herein are the private ones of the writers and are not to be construed as official or

reflecting the views of the Navy Department or the naval service at large.

Primary funding for the research was from the Harbor Branch Foundation, Fort Pierce, Florida, with partial support from the National Institutes of Health grants HL 7896-11 and HL 12157.

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Table 1.

DUKE SATURATION DECOMPRESSION PROFILE

